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Systematic Dynamics Analysis of Coal City Coordination Development

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Abstract

Based on the analysis of system structure of the coal city, using system dynamics approach, the system dynamics model of coal city coordination development has been established. Through sensitivity examination, it is discovered that the coal city system output performs staggering difference when the policy and sensitivity parameters are changed such as the environment harness fixed investment rate and the gangue use factor. Through changing the controls parameter the state variables linear instability is analyzed. Taking Zhaozhuang as example for qualitative investigation, it can be found that nearby dynamics linear instability, there are many stable models and few unstable models such as the atmospheric environment government investment, and the non-coal industry fixed investment. Those unstable models are order parameters for current Zaozhuang development.

Keywords: Coal city; Coordinated development; System dynamics; Linear instability

1. Introduction

Since the System Dynamics was established by professor Jay.W.Forrester since 1960, its theory and method are applied to city system study by many scholars: Weimin Zhang evaluates the present level of sustainable development of Beijing[1]; Chuanmin Wang uses the systematic dynamics method to guide the leading industry choice[2]; Xiaoqing Huang sets up a model for coordinate development which contains three interacting and interdependent subsystems: ulation, jobs and houses[3]. Most of the researches are insufficient in the aspect of coal city. Displays in the following aspects: (1) Had not emphasized in the syetem design that the coal city has a serious dependence on the coal resource; (2) Coal city development

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life cycle and evolution process displays not obviously when they are simulated; (3) There is large difference from what factors are control action in coal city evolution.

In this paper, it is point that the coal industry develops to an extent that the coal resource's supply is obviously deficient and the surrounding environment's waste receptivity reduces gradually, the environment and resources then become the scarce factors of coal industry's sustainable development and also become the scarce essential elements, which hinder, and is the important endogenous variables and the rigid constraints of the coal city development.

Through sensitivity examination of dynamics model of the coal city coordination development systems, the policy parameters and sensitive parameters are changed, according to the output result, there are three forms in the coal city system development models: non-recycling economic development pattern depending on the coal resource, fast economy development model and coordination development model. Different development models result in different linear stability of coal city evolution development. Through model simulation, the conclusion is that the coordination development is the best choice of the coal city development strategy.

2. Coal city System Structure

Starting with the macrostructure of coal recycling economic system, the paper takes the system dynamics as a tool, constructs a basic feedback structure of the whole coal urban system and reflects the basic process of coal urban development evolution with the goal of coal city's sustainable development.(See fig.1)

To research coal city and analyze the coal industry's function and reaction towards the coal city, the following subsystem should be included: the population subsystem, economical subsystem, resources subsystem, environment subsystem.These four sub-systems influence, restrict, interact with each other, through their mutual input and output variable, to complete the coal urban system's evolutional development together. According to the modeling goal as well as the exchange relations of material and information among each sub-block, the systemboundary is determined especially as follows:

(1) Urban population quantity and growth and the population quality;

(2) The coal resource condition;

(3) The coal city water resources condition;

(4) The coal city land resource condition;

(5) The energy consuming of unit output value and the situation of energy saving and emission reduction;

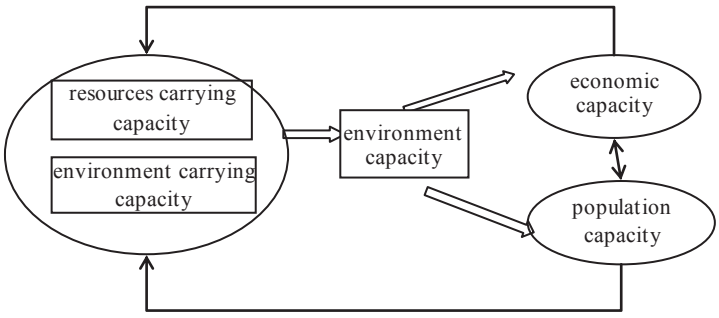

Fig.1 The framework of the cooperative development of systems in coal city

(6) The exhaust gas discharging condition, the waste water emission status and the utilizing condition of solid waste;

(7) The coal city's economy condition.

3. System Dynamic Model

3.1. Model constructing

From Fig.2, it is concluded that there are mainly three cross-module feedback loops in the model:

(1) The feedback relation between atmospheric environment and coal industry GDP. Along with the change, the feedback loop transforms from positive feedback to negative feedback. The key point of solving the problem lies in changing the coal industry's production method, carrying on the industrial upgrade and update and changing the increasing air pollutant discharge condition.

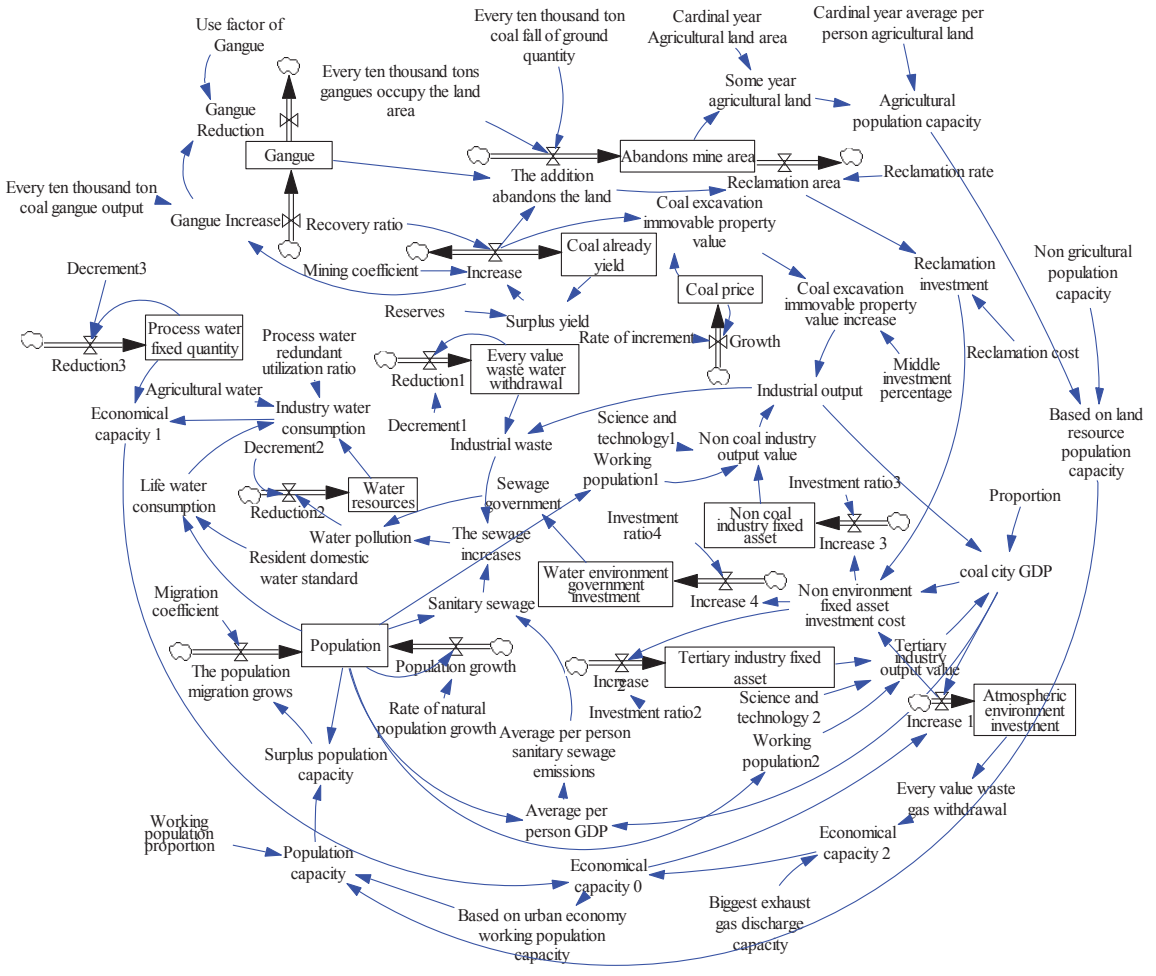

Fig. 2 Complex Diagram of Coal Industry

(2) The positive feedback relation between coal resource and coal city economic sustainable development. The coal city's industrial output value is influenced by the coal mining and processing output value. The possibility of this situation is closely related to the status of coal mining and processing industry in the coal city's economy; the higher the proportion, the stronger the dependence of coal city upon the coal mining and processing industry and the bigger the change's possibility.

(3) The negative feedback relations among the coal city and various systems of population, economy and environment. There are two key points for this feedback to form the negative feedback: First, whether the economic capacity based on water resources is the primary factor to decided the coal city's final economic capacity; Second, the population growth has certain inertia property: the decrease of urban population capacity cannot suppress the population quantity to increase immediately.

3.2. Establishment of functional relations and parameter among model variables

To simplify the coal city's coordination development system, and select 12 state variables like population, 15 rate variables like the increase of coal resource mining and 20 subsidiary variables like the coal available yield. According to the system dynamics frame of coal city coordination development, the correlation of various module variables is obtained after being analyzed based on the overall statistical survey and statistical data collection; and the relative parameter and model are established, drawing lesson from the mature formula and parameter that already have the research results, and then the dynamics model of coal urban system is constructed finally.

There are altogether three kinds of methods to determine to assure the model parameter as follows:

First, arithmetic mean method. If the variables have long and relative stable relations, it is advised to carry on the data statistics by means of system history and definite the parameter value, for example, natural population growth, water resources decrement rate and so on, with arithmetic mean method.

Second, trend extrapolation method. Based on parameter nature and statistical data, select different types of formula and take the recursion according to the proportion, for example, the non-environment fixed assets investment, non-coal industry jobholders' amount and so on.

Third, regression analysis method. In the model, many kinds of regression analysis methods are adopted in quantity to determine the correlations of parameters. For example, use the multi-element nonlinear regression to set the the tertiary industry output value, the fixed assets investment of atmospheric environment improvement and so on.

3.3. Model checking

The imitation computation work of coal city coordination development system is completed with the help of VENSIM PLE tool. And each target's forecasting target value of the evaluating coal city at each time point in the stimulation period is gained. To confirm the model's validity, the operation result of the model could be checked.

(1) The consistency check between model behavior and actual system. This paper defines the time boundary from 1998 to 2020. It is advised to take various systematic factors of Zaozhuang in 1998 as the base period; the data before 2008 is used to check the model and parameter, while the data after 2008 is used to forecast.

The checking result indicates that the simulation result of Zaozhuang coordinated development dynamic system is basically consistent with the actual state, the relative error of target simulation value and realistic value mostly situates between -5.00% and 5.00%.Therefore, the system model's behavior reflects the structure and condition of coal city system more realistically in general and the fitting

precision is high; then it can be taken as a simulation and prediction method for the coordination developing process of coal city system.

(2) The sensitivity examination of model system. It is discovered that the model's behavior is influenced bigly by partial systematic policy parameters which all locate the interface points of many feedback loops. These policy parameters mainly include fixed assets investment scale coefficient, industrial water reuse ratio, the gangue use rate, the recovery rate, the land reclamation rate and so on. These parameters are either the impelling force of coal city coordination development or the important target of evaluating the coal city. Through the regulation and control of systematic policy parameter, the evolutional tendency of coal city system could be simulated and imitated.

(3) The suitability and consistency check of model structure. On one hand, during the modeling process, the feedback structure and dynamic equation that conforms to the characteristic of coal city are built on the basis of analyzing the structure of coal city coordination development system[1-3]. The determination of the parameter in the model is obtained directly from the historical statistical data or by consulting relational data and the model structure also conforms to the actual system's basic condition; On the other hand, the structure consistency check of coal city's coordination development dynamics model is conducted with the help of Vensim PLE software's own equation and dimension examination functions; the conclusion is that the equation in the model is correct, and the dimension is consistent.

4. Simulation Analysis of Zaozhuang Coal City System

The operation of coal city systematic dynamics model is simulated based on data information of Zaozhuang city, and the result is as follow figers:

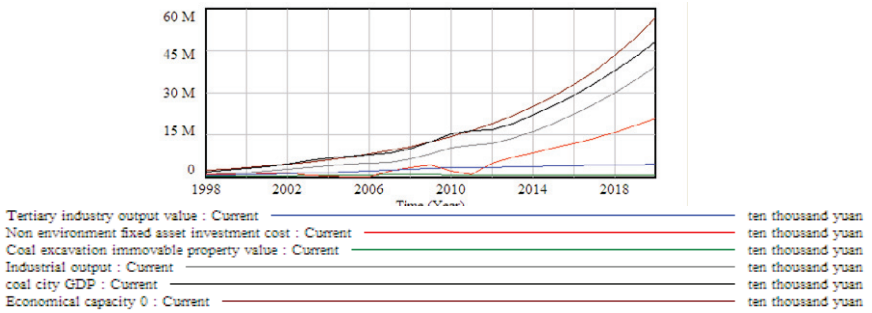

Fig.3 The simulation of economy system about coal city

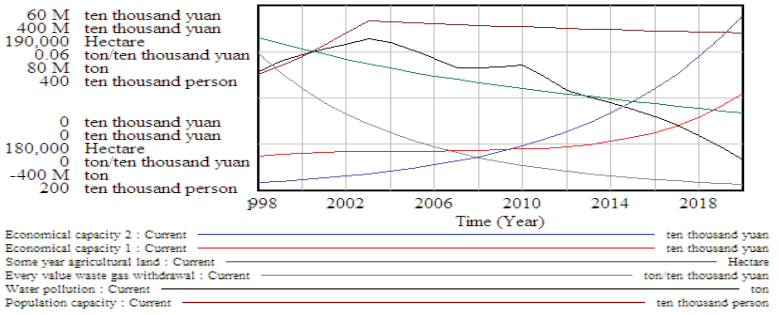

Fig.4 The simulation of the system of population-economy-environment-resources about coal city

Through the analysis of the simulation result, the following conclusion could be obtained:

(1) If the coal excavating industry accounts for a small GDP proportion of coal industry, the coal resource depletion will have little effect on the growth of the coal industry GDP.

(2) In the coal city, the non-environmental fixed investment has an obvious effect on the economic growth.and cause the coal industry GDP to grow unstably. Furthermore, the hysteresis effect between fixed assets investment and economic growth could be discovered from Figure 3.

(3) When the coal city GDP surpasses the economic capacity determined by environmental capacity limit, the economic growth will postpone until returns to a scope that the economic capacity allows.

(4) Because of the land collapse, the gangue occupying the land and others, the agricultural lands reduce year by year, which will cause the population capacity to reduce.

(5) As the industrial economic development brings about water pollution, the two aspects act the which are water environment improvement's investment and industrial value cause the water pollution degree to increase first and drop then.

(6) As the industrial economic development brings about the air pollution, the continual investment of atmospheric environment improvement fixed asset makes the coal industry's unit output value gas withdrawal volume drop unceasingly.

(7) The water body pollution causes the total quantity of water resources to reduce, and the economic capacity 2 limited by water resources quantity changes correspondingly; in a similar way, under the situation of assuring the coal industry's atmospheric environment capacity, the drop of unit output value waste gas withdrawal makes the coal industry's economic capacity 1 increase continuously.

(8) According to "the worst (smallest) factor limiting law", it is expressed concretely: Coal industry economic capacity=min(economic capacity 1, economic capacity 2)

5. Linear Instability Analysis of Coal City Coordination Development

Chang the sensitivity examination of systematic dynamic model of coal city coordinated development, the export presents an enormous difference. Through adjusting the sensitive parameters of Zaozhuang coordinated development system and taking advantage of its parameter's different combination and disposition, the author of this paper simulates three different models of the development in Zaozhuang, in other words, non-circular economy model A that depends on the coal resource badly, economic rapid development model B and coordinated development model C. These three patterns' sensitive parameters could be found in Table1.

Table 1 Sensitive parameters of three models

	Parameter Value				*Parameter Value*		
	A	B	C		A	B	C
Non-coal Industry Investment Rate	20%	60%	50%	Tertiary Industry Investment Rate	15%	25%	35%
Water Environment Improvement Investment Rate	0.05%	0.08%	0.18%	Atmospheric Environment Investment Rate	0.05 %	0.1%	0.15 %
Reclamation Rate	0.2	0.6	1	Water Reuse Rate	0.3	0.7	1
Recovery Rate	0.35	0.6	0.85	Gangue Use Rate	0.2	0.6	1
Coal Mining Coefficient	0.08	0.05	0.03				

According to the export result, the development model of coal city system is divided into three forms, and the linear stability of coal city evolution development is different for different development model.

First, the non-recycling economic model that relies on the coal resource seriously; in this model, the coal excavating industry's output value accounts for over 35% of the industrial output value; the management of resources mining is disordered, the waste is serious, the environmental investment accounts for a low proportion and the urban environment quality is bad. From the model's systematic dynamics simulation, it can be discovered that the coal city GDP appears a shape of "parabola" that rises first and falls later (see Fig. 5).

Second, the coordinated development model. The pattern owns the self-organizing characteristics that under the function of recycling economy, the subsystems of population, resources, environment and economic organize, plan overly and coordinate spontaneously; the urban GDP assumes an exponential growth (see Fig.6); its function form is entity positive value and the system appears an unstable characteristic.

Third, the economic rapid development pattern. In this pattern, the design of model is controlled by coal city environment capacity, the following elastic feedback loop of coordination is realized: not coordinate---increase the environmental investment---coordinate---reduce environmental investment---coordinate. That is, the coal city GDP's evolution bears a trend of linear stability---recycling economy---linear stability--- exponential growth--- linear stability. The coal city development has the development characteristic of spiral-shaped rising, which implies that the recycling economy is significant for the coal city system sustainable development.

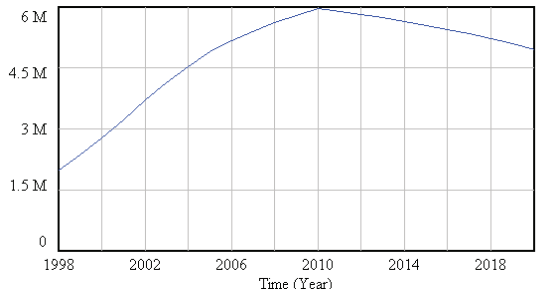

Fig.5 The trend of GDP of non-cycling economic model dependent on coal resources

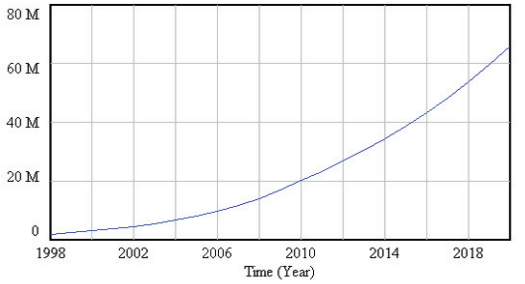

Fig.6 The trend of coal city GDP of cooperate development model

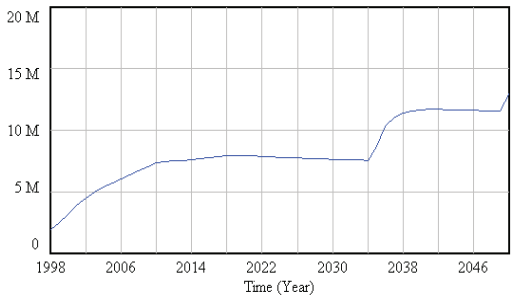

Fig.7 The trend of coal city GDP of rapidity economic growth model

6. The choice of development models in Zaozhuang

(1) In the non-circular economy model that depends on the coal resource will lead to the resources exhaustion, economic recession, depopulation and environmental deterioration of coal city finally, so the model is not advised to adopt.

(2) The economic rapid development model is guided by the economic development, but the economic subsystem does not coordinate with the development of resources, environment and population subsystems, which results in the fluctuate and unstable property in the economic development.

(3) Based on the recycling economic, the coordinated development model pays great attention the environmental protection, the adjustment of industrial structure and resources high-effective use. So it becomes the first selection of Zaozhuang urban development pattern.

(4) Comparing the statistical target of Zaozhuang economic and social development in 2007 and Zaozhuang urban systematic development targets under three models, the author of this paper discovers that: at present, Zaozhuang city's urban development situates a stage between economic high-speed growth and coordinated development; in future, the development should be evolved to the coordinated development; the environmental investment and the investment of industrial restructure adjustment guidance should be paid more attention; its breakthrough point is the construction of recycling economy ecological industrial chain

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